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# FLYING WEATHER IN THE SOUTHERN PLAINS STATES.

By JOHN A. REIHLE, METEOROLOGIST.

[Aerological Station, Broken Arrow, Okla., November 18, 1920.]

SYNOPSIS.

This paper is a study of wind and weather as they affect the business of flying. Tables of average free-air winds have been computed for the first two years of pilot balloon observations at Broken Arrow and Fort Sill, Okla., and for one year at Fort Omaha, Nebr. The annual means are based on 1,237 observations at Broken Arrow, 1,098 at Fort Sill, and 567 at Fort Omaha. By applying to the mean velocities the mean gradients from each level to the next higher level from the surface up, discontinuities due to fewer observations at higher altitudes have been to a large extent eliminated. Average directions were computed separately by trigonometry.

Because balloon ascents are made at times when the wind is too light for kite flights, a comparison of mean velocities obtained by kites and balloons shows a slightly smaller mean velocity in summer by balloons. Another fact brought out is that the direction at high altitudes at both Oklahoma stations has a stronger northerly component in summer than in any other season.

The general eastward drift of the air at high altitudes is conspicuous at all stations; marked differences, however, occur from time to time under similar surface pressure distribution, and these differences are largely the result of abnormal surface temperatures.

Velocities in the free air are somewhat smaller over Oklahoma than at stations farther north and this fact, together with the comparatively mild winters, is favorable for the growth of aviation in this region. Transcontinental flying, too, can be continued throughout the year at this latitude while a considerably more northerly route would often be closed by inclement weather.

Low clouds and rain constitute the most frequent unfavorable condition for flying; fog is serious, but too infrequent to be of importance; while high winds are of intermediate importance.

## INTRODUCTION.

The economic importance of the wind in commercial aeronautics calls for complete data on this meteorological element based on a systematic distribution of regular observations. This work was started years ago in this country, but received added impetus when wind observation by means of pilot balloons was begun by the Signal Corps during the war. These observations are now conducted by the Weather Bureau as a part of the permanent work of aerological investigations. The records have added much to our knowledge of the seasonal and geographical distribution of the winds in the free air, and will be of increasing value with the growth of aviation.

Pilot balloons furnish, perhaps, the most available method for measuring the wind aloft for flying purposes, their usefulness being precluded only by the conditions that interfere with flying, namely, fog, low clouds, and precipitation. They have the advantage over kites in that either very high or very low velocities may be measured, while kites can not rise through a calm stratum and are blown away if the wind is too strong. Furthermore, the data are quickly available after the observation is made.

## AVERAGE WINDS ALOFT.

The means of velocity and direction for Broken Arrow and Fort Sill, Okla., and Fort Omaha, Nebr., are given in Tables 1, 2, and 3. Broken Arrow records are for the period November, 1918, to October, 1920, inclusive; Fort Sill, for July, 1918, to July, 1920; and Fort Omaha, for December, 1918, to November, 1919. The number of observations for each season and for the year on which Tables 1 to 3 are based is given in Table 4. Broken Arrow records were computed to an altitude of 6,000 meters, but on account of a smaller number of observations at high altitudes at the other two stations the records were computed to 4,000 meters only.

TABLE 1.—*Mean free-air winds at Broken Arrow, Okla.,*[1] *latitude, 36° 2′ N.; longitude, 95° 49′ W.; elevation, 233 meters.*

| Altitude (meters). | Spring. | | Summer. | | Autumn. | | Winter. | | Annual. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. |
| | | m/s. | | m/s. | | m/s. | | m/s. | | m/s |
| Surface | S. 19° E. | 6.8 | S. 16° E. | 4.6 | S. 19° E. | 5.6 | S. 63° W. | 6.3 | S. 7° E. | 5.8 |
| 250 | S. 3° W. | 8.5 | S. 7° W. | 6.3 | S. 3° W. | 8.1 | S. 76° W. | 7.9 | S. 15° W. | 7 7 |
| 500 | S. 19° W. | 9.8 | S. 17° W. | 6.8 | S. 15° W. | 9.2 | S. 85° W. | 9.3 | S. 29° W. | 8.8 |
| 750 | S. 36° W. | 10.2 | S. 22° W. | 6.7 | S. 27° W. | 9.3 | S. 87° W. | 10.0 | S. 41° W. | 9.0 |
| 1,000 | S. 54° W. | 10.4 | S. 26° W. | 6.5 | S. 36° W. | 9.3 | N. 87° W. | 10.8 | S. 51° W. | 9.3 |
| 1,500 | S. 73° W. | 10.8 | S. 34° W. | 6.2 | S. 63° W. | 9.2 | N. 80° W. | 11.8 | S. 69° W. | 9.5 |
| 2,000 | S. 87° W. | 11.7 | S. 51° W. | 6.0 | S. 78° W. | 9.7 | N. 78° W. | 13.4 | S. 82° W. | 10.2 |
| 2,500 | N. 86° W. | 13.2 | S. 75° W. | 6.1 | S. 84° W. | 10.1 | N. 77° W. | 14.6 | N. 89° W. | 11.0 |
| 3,000 | N. 83° W. | 14.7 | N. 83° W. | 6.5 | S. 89° W. | 10.6 | N. 76° W. | 16.5 | N. 81° W. | 12.1 |
| 3,500 | N. 80° W. | 16.2 | N. 67° W. | 6.7 | N. 89° W. | 11.5 | N. 78° W. | 18.0 | N. 79° W. | 13.1 |
| 4,000 | N. 82° W. | 17.2 | N. 50° W. | 7.0 | N. 79° W. | 12.6 | N. 74° W. | 19.0 | N. 72° W. | 14.0 |
| 4,500 | N. 83° W. | 19.1 | N. 45° W. | 7.6 | N. 76° W. | 13.5 | N. 70° W. | 20.8 | N. 68° W. | 15.2 |
| 5,000 | N. 75° W. | 20.3 | N. 44° W. | 7.6 | N. 71° W. | 14.8 | N. 65° W. | 21.8 | N. 62° W. | 16.1 |
| 6,000 | N. 74° W. | 22.5 | N. 48° W. | 9.2 | N. 58° W. | 17.3 | N. 60° W. | 24.5 | N. 58° W. | 18.4 |

[1] To change meters per second to miles per hour multiply by 2.236932, or 2¼ approximately. Directions are recorded as the point from which the wind comes; e. g., a west wind is one from the west.

TABLE 2.—*Mean free-air winds at Fort Sill, Okla.,*[1] *latitude, 34° 40′ N.; longitude, 98° 25′ W.; elevation, 355 meters.*

| Altitude (meters). | Spring. | | Summer. | | Autumn. | | Winter. | | Annual. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. |
| | | m/s. | | m/s. | | m/s. | | m/s. | | m/s |
| Surface | S. 1° W. | 5.4 | S. 19° E. | 3.8 | S. 26° E. | 3.8 | N. 66° W. | 5.2 | S. 9° E. | 4.6 |
| 250 | S. 11° W. | 8.2 | S. 1° W. | 7.0 | S. 5° E. | 7.6 | N. 75° W. | 7.4 | S. 12° W. | 7.6 |
| 500 | S. 24° W. | 9.9 | S. 5° W. | 8.8 | S. 16° W. | 9.2 | N. 79° W. | 9.0 | S. 27° W. | 9.2 |
| 750 | S. 36° W. | 9.7 | S. 12° W. | 8.5 | S. 19° W. | 9.6 | N. 86° W. | 9.6 | S. 34° W. | 9.4 |
| 1,000 | S. 43° W. | 9.6 | S. 19° W. | 7.7 | S. 30° W. | 9.4 | W. | 10.3 | S. 43° W. | 9.3 |
| 1,500 | S. 58° W. | 10.7 | S. 28° W. | 6.9 | S. 62° W. | 8.8 | N. 86° W. | 11.1 | S. 57° W. | 9.4 |
| 2,000 | S. 69° W. | 12.2 | S. 28° W. | 6.7 | W. | 9.0 | N. 80° W. | 11.8 | S. 69° W. | 9.9 |
| 2,500 | S. 77° W. | 14.4 | S. 49° W. | 6.5 | N. 88° W. | 9.3 | N. 84° W. | 12.9 | S. 81° W. | 10.7 |
| 3,000 | N. 87° W. | 15.0 | S. 61° W. | 6.6 | N. 76° W. | 10.6 | N. 82° W. | 14.8 | N. 81° W. | 11.7 |
| 3,500 | N. 87° W. | 15.8 | N. 2° W. | 7.7 | N. 75° W. | 11.1 | N. 80° W. | 16.2 | N. 77° W. | 12.7 |
| 4,000 | N. 78° W. | 17.8 | N. 36° W. | 7.9 | N. 74° W. | 11.7 | N. 76° W. | 17.8 | N. 70° W. | 13.8 |

[1] To change meters per second to miles per hour multiply by 2.236932, or 2¼ approximately. Directions are recorded as the point from which the wind comes; e. g., a west wind is one from the west.

TABLE 3.—*Mean free-air winds at Fort Omaha, Nebr.,*[1] *latitude, 41° 20′ N.; longitude, 96° 00′ W.; elevation, 350 meters.*

| Altitude (meters). | Spring. | | Summer. | | Autumn. | | Winter. | | Annual. | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. |
| | | *m/s.* | | *m/s.* | | *m/s.* | | *m/s.* | | *m/s* |
| Surface | E. | 5.5 | S. 23° E. | 3.9 | S. 40° W. | 5.2 | S. 82° W. | 5.5 | S 14° W. | 5.0 |
| 250 | S. 54° E. | 9.0 | S. 1° E. | 6.9 | S. 43° W. | 7.7 | N. 80° W. | 8.7 | S. 36° W. | 8.0 |
| 500 | S. 38° E. | 9.9 | S. 10° W. | 7.7 | S. 58° W. | 9.3 | N. 77° W. | 10.4 | S. 48° W. | 9.3 |
| 750 | S. 43° W. | 10.0 | S. 22° W. | 7.8 | S. 70° W. | 9.8 | N. 87° W. | 11.2 | S. 60° W. | 9.7 |
| 1,000 | S. 67° W. | 10.1 | S. 37° W. | 8.1 | S. 80° W. | 10.4 | N. 81° W. | 11.9 | S. 71° W. | 10.1 |
| 1,500 | S. 89° W. | 10.4 | S. 57° W. | 8.8 | S. 89° W. | 11.4 | N. 69° W. | 13.5 | S. 89° W. | 11.0 |
| 2,000 | N. 85° W. | 11.6 | S. 80° W. | 9.4 | N. 84° W. | 11.8 | N. 65° W. | 14.5 | N. 85° W. | 11.8 |
| 2,500 | N. 80° W. | 13.0 | N. 84° W. | 10.1 | N. 71° W. | 14.1 | N. 66° W. | 15.9 | N. 74° W. | 13.3 |
| 3,000 | N. 86° W. | 13.7 | N. 88° W. | 11.1 | N. 71° W. | 15.1 | N. 64° W. | 17.3 | N. 76° W. | 14.3 |
| 3,500 | N. 79° W. | 15.8 | N. 79° W. | 11.2 | N. 72° W. | 15.9 | N. 62° W. | 18.9 | N. 71° W. | 15.5 |
| 4,000 | N. 67° W. | 16.3 | N. 71° W. | 11.9 | N. 81° W. | 16.8 | N. 70° W. | 20.6 | N. 74° W. | 16.4 |

[1] To change meters per second to miles per hour multiply by 2.236932, or 2¼ approximately. Directions are recorded as the point from which the wind comes; e. g., a west wind is one from the west.

TABLE 4.—*Number of observations on which are based the mean values given in Tables 1, 2, and 3.*

| Altitude. | Broken Arrow, Okla. | | | | | Fort Sill, Okla. | | | | | Fort Omaha, Nebr. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring. | Summer. | Autumn. | Winter. | Annual. | Spring. | Summer. | Autumn. | Winter. | Annual. | Spring. | Summer. | Autumn. | Winter. | Annual. |
| Surface | 317 | 344 | 297 | 279 | 1,237 | 293 | 318 | 241 | 246 | 1,098 | 139 | 158 | 132 | 138 | 567 |
| 250 | 317 | 344 | 291 | 278 | 1,230 | 292 | 317 | 241 | 245 | 1,095 | 138 | 158 | 130 | 138 | 564 |
| 500 | 308 | 338 | 279 | 260 | 1,185 | 276 | 315 | 230 | 236 | 1,057 | 134 | 155 | 128 | 127 | 544 |
| 750 | 290 | 328 | 263 | 250 | 1,131 | 258 | 306 | 210 | 219 | 993 | 124 | 154 | 118 | 107 | 503 |
| 1,000 | 267 | 322 | 259 | 243 | 1,091 | 231 | 296 | 198 | 203 | 928 | 114 | 144 | 110 | 106 | 474 |
| 1,500 | 223 | 299 | 239 | 221 | 982 | 189 | 275 | 152 | 179 | 795 | 88 | 115 | 96 | 85 | 384 |
| 2,000 | 188 | 270 | 217 | 192 | 867 | 155 | 228 | 124 | 150 | 657 | 67 | 77 | 72 | 72 | 288 |
| 2,500 | 147 | 232 | 188 | 170 | 737 | 124 | 174 | 94 | 125 | 517 | 45 | 55 | 45 | 55 | 200 |
| 3,000 | 121 | 212 | 168 | 153 | 654 | 99 | 136 | 77 | 100 | 412 | 30 | 45 | 41 | 37 | 153 |
| 3,500 | 91 | 185 | 150 | 132 | 558 | 85 | 120 | 66 | 80 | 351 | 22 | 35 | 31 | 27 | 115 |
| 4,000 | 80 | 159 | 122 | 112 | 473 | 68 | 97 | 58 | 72 | 295 | 15 | 28 | 25 | 18 | 86 |
| 4,500 | 62 | 131 | 106 | 80 | 379 | | | | | | | | | | |
| 5,000 | 52 | 121 | 96 | 69 | 338 | | | | | | | | | | |
| 6,000 | 37 | 104 | 77 | 46 | 264 | | | | | | | | | | |

The seasonal means for Broken Arrow are shown graphically in figure 1, and the annual frequency of directions in percentages is shown for various levels in figure 2. The percentage frequencies of a west component at Broken Arrow at the surface, and at 1, 2, 4, and 6 kilometers are 46, 70, 78, 80, and 80, respectively; at the surface, and 1, 2, and 4 kilometers, these are for Fort Sill: 46, 68, 74, and 72, and for Fort Omaha: 53, 74, 86, and 94. A decrease in the preponderance of westerly winds with decreasing latitude is thus to be seen. (Cf. also Table 10, reference 2.)

*Reliability of the data.*—Most of the records here used were obtained by the one-theodolite method, the ascensional rate of the balloon being computed by a formula based on the weight and free lift of the balloon. Accuracy of the records therefore depends on whether the balloons rise at the rate computed. It has been shown (1) that the error in the rate of ascent under stable conditions of the air is negligible. When convection is active, as on summer afternoons, the error may be large in the lower layers, and it is necessary to use two theodolites to get accurate records. Convection nearly always displaces the balloon upward; downward displacements are usually weak.

Tables 1 to 3 are based on two daily observations taken, whenever weather permitted, at 7 a. m. and 3 p. m. (90 meridian time). These observations occur near the time of the minimum and maximum surface wind, and represent a close approach to the daily mean. During the two-year period 87 per cent of the possible number of observations were taken at Broken Arrow, excluding part of the time when Sunday morning runs were not made. The seasonal distribution is therefore good, although a somewhat higher percentage of observations was made during summer than winter.

The means for Broken Arrow and Fort Sill are very similar and are believed to be essentially accurate for the period covered. There are, no doubt, appreciable errors in some of the individual observations, but they have been

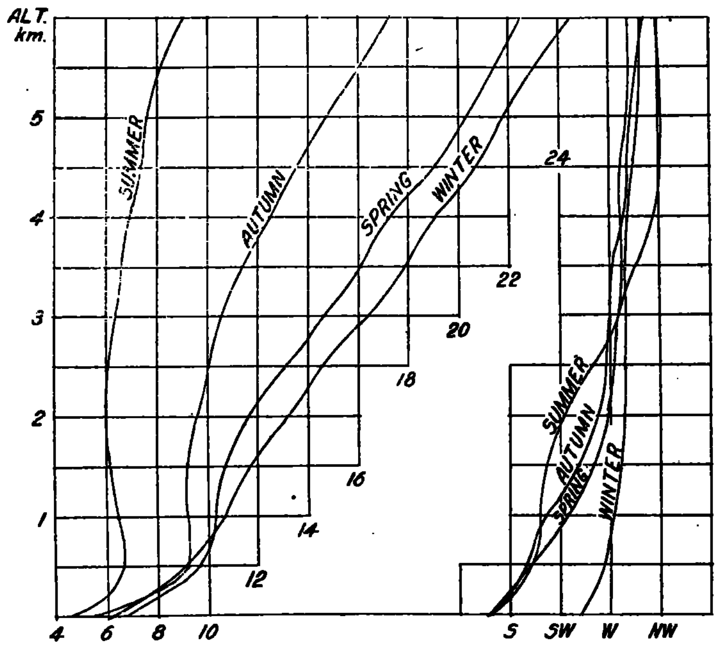


FIG. 1.—Mean seasonal free-air wind velocity (m/s) and direction, at Broken Arrow, Okla.

largely if not entirely eliminated by the large numbers used. The largest source of error—the disturbing effect of convection on the rate of ascent of the balloon on summer afternoons—was largely overcome by using two theodolites.

The question as to whether the two years were normal years and therefore the winds represent normal conditions can be determined only after a longer period of observations is available. It is not probable, however,

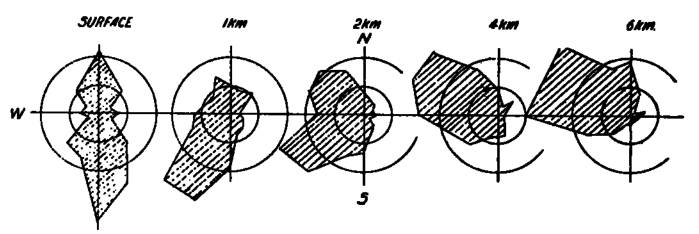


FIG. 2.—Annual mean frequency of direction at Broken Arrow, Okla. Circles represent 5 and 10 per cent, respectively, of the total from any one of the 16 points.

that normal winds will be greatly different from the conditions here depicted. The departure of a short period from normal is evident from the direction in the lower levels in spring at Fort Omaha, where the means are based on one year only. The strong easterly component in the spring of 1919 is also evident at Broken Arrow and Fort Sill, but its effect is obscured at the latter places by another year's record.

A comparison of the published means of wind from kite records at Drexel, Nebr. (2), aside from the difference resulting from geographical location, reveals, as was expected, smaller velocities at all altitudes in summer. This is due in the first place to the fact that part of the time the wind is too light to support a kite; and secondly, kite flights are made in the morning on many days when there is little wind near the ground in the afternoon.[1]

Another difference in the comparison is that although kite records show a southerly component at all altitudes in summer, balloon records show a stronger northerly component over Oklahoma at high altitudes in this season than in any other. The most common summer condition is a moderate south wind in the lower layers, above which is a rather deep layer of light wind, with northwesterly winds at still higher altitudes.

The Southern Plains States lie well to the south of the average storm tracks. Winters are comparatively mild, and a large proportion of the time throughout the year is favorable for aviation. Surface winds blow very steadily from the south during the summer; but during the winter there is nearly a balance between the north and south winds, with the result that winter means at

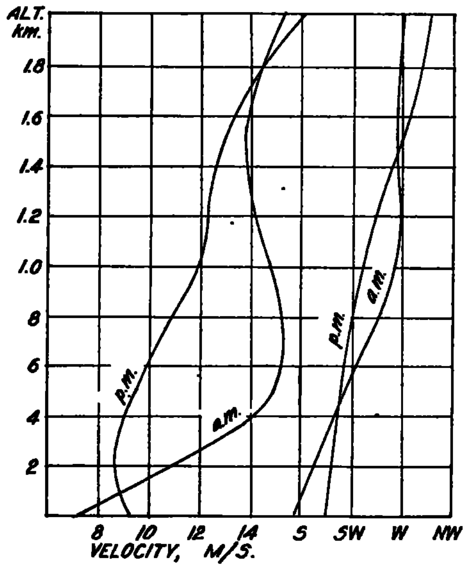


FIG. 3.—Mean 7 a. m. and 3 p. m. wind velocity and direction at Broken Arrow, Okla., for March, 1920.

Broken Arrow show a southerly component and those at Fort Sill a slight northerly component. The depth of the southerly component increases from winter to summer, and velocities decrease at the same time.

A rapid increase in velocity from the ground to approximately 500 meters occurs at all seasons; above this there is little or no increase to 1,500 meters, and there may be a decrease as occurs in all seasons except winter at Fort Sill. Above 1,500 meters there is a nearly constant increase to at least 10 kilometers. The decrease in velocity above 500 meters is sometimes caused by a rapid shift in direction, but occurs also when there is little or no change in direction. It is not the result of convection because it is most marked in the early morning (fig. 3) when vertical currents are at a minimum. No satisfactory explanation of this phenomenon has been found, but it is suggested that surface pressure systems, which exert a shallow influence in this region, may interact with the general circulation to interrupt the normal increase aloft.[2]

Westerly winds, as is generally known, increase with altitude; easterly winds continue light to an indefinite altitude or shift to west. This shift may be a gradual veering through south and southwest, or a sharp line may divide the lower easterly and the overrunning westerly winds. A detailed discussion of the turning of the winds with altitude will be found in MONTHLY WEATHER REVIEW, January, 1918 (3). The deductions there made concerning the effect of passing HIGHS and LOWS are equally applicable for this region.

## CHANGES—ANNUAL, DIURNAL, AND IRREGULAR.

The march of the wind has three characteristics—annual, diurnal, and irregular. The annual march is shown in the tables, and in figure 1. Highest velocities occur in winter, except that in the first kilometer they may occur in spring; lowest velocities at all altitudes occur in summer.

The diurnal change is shown in figure 3, which is a graph of the a. m. and p. m. means at Broken Arrow during March, 1920, a period of unusally strong winds. During the early morning an observation of the surface wind gives little indication of the wind aloft. Figure 4, a horizontal projection of the balloon's path on the morning of September 18, 1920, during anticyclonic weather, gives an idea of the infinite variety of changes that occur in the free air from day to day. In the morning the velocity may increase from light on the ground to gale force within a few hundred meters. On the morning of March 27, 1920, the wind increased from 8.5 m/s at the surface to 30 m/s at 500 meters and 34 m/s at 900 meters. During the day convection and turbulence tend to remove such irregularities and to bring about nearly the same direction and velocity throughout the first kilometer, as illustrated in figure 3.

Irregular changes in velocity at any level are the result of changes in the horizontal pressure gradient at that level. Winds near the ground result from passing HIGHS and LOWS, but at moderate altitudes the free-air winds are determined primarily by the surface temperatures, and the cause of abnormal winds aloft is generally to be found in an abnormal surface temperature distribution, in its effect on the free-air pressure distribution.

## ABNORMAL WINDS ALOFT.

Present-day aviation is most concerned with the winds of the first 2 kilometers, but in view of the discussion among fliers of the possibility of flying at enormous speeds by taking advantage of the winds at high altitudes a brief summary of these winds seems desirable. During the two years' record at Broken Arrow 71 balloons have been observed to the 10-kilometer level (32,808 feet), and the velocities found there are certainly ample to carry the flier well on his way provided he can maintain the altitude. By applying the gradients from 6 to 10 kilometers to the velocities at 6 kilometers, the velocities indicated for 10 kilometers are: Spring, 38 m/s.; summer, 17 m/s.; autumn, 28 m/s.; and winter, 47 m/s. The number of winter observations is too small to afford entirely reliable means, but the annual mean, 33 m/s.,

[1] Values for the other three seasons and the means for the year agree closely at Drexel and at Fort Omaha, those at the latter averaging about 1 m. p. s. lower than those at Drexel. (See Table 6, reference 3, and Table 3, this paper.) The two stations are about 30 kilometers apart.—W. R. G.

[2] Thus in the lower layers easterly winds are nearly as frequent as westerly winds (see fig. 2). The latter ordinarily increase in speed with altitude rather gradually during the summer, but the former almost invariably die out completely shortly after the 500-meter level is reached. The average of the *sharp* decrease in velocity of easterly winds and the *moderate* increase in velocity of westerly winds results in the *slight* decrease noted in the mean values for the summer season, Tables 1 to 3.—W. R. G.

agrees quite well with the determination of cirrus cloud movements at Blue Hill and Washington (4). The percentage of westerly winds has decreased somewhat, but this is more apparent than real, because the balloon rising in a west wind generally passes beyond the range of visibility before reaching this altitude.

But even the strong westerlies of winter are interrupted at intervals by light winds which at times have an easterly direction so that the aviator who is equipped for high-altitude flying and desires to use the strong westerlies is still dependent on the meteorologist for the prediction of their occurrence.

Examples of abnormal winter winds are found in Table 5. High-altitude easterly winds at this season, as occurred on the morning of January 29, 1919 (columns 1 and 2), are unusual. These easterly winds continued with decreasing altitude through the afternoon and during the next day, gradually giving way to the prevailing west wind. On the morning of December 14, 1919 (columns 3 and 4), the wind was abnormal in that it was unusually high. Starting with almost a calm at the surface the

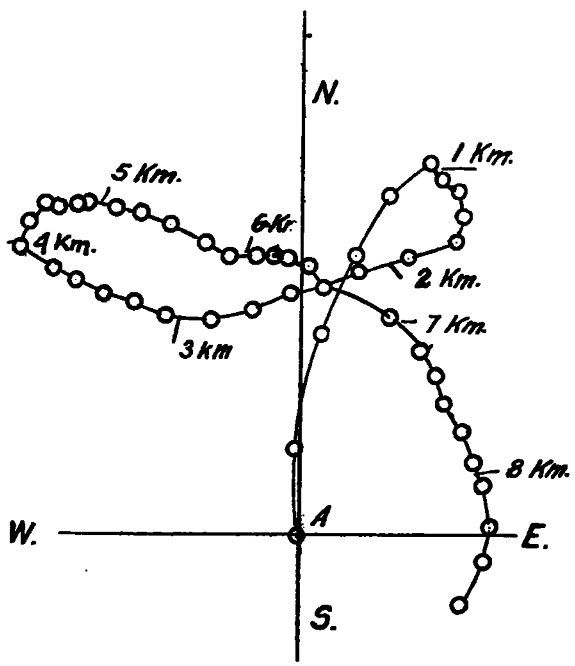


FIG. 4.—Horizontal projection of balloon's path, Broken Arrow, Okla., 7:55 a. m., Sept. 18, 1920. Small circles mark consecutive minutes. A, observation point. Scale: 1 centimeter, 400 meters.

wind increased steadily to a velocity of 50 m/s. (112 m. p. h.) at 5,400 meters. These two observations were made under similar surface pressure distribution, i. e., there was a ridge of high pressure over the West and South, with low pressure over the North and East. It is therefore evident, as stated by Mr. Gregg, that "Surface pressure systems have little influence in this respect except in so far as they produce modifications in the surface temperature distribution. * * * The relation between the surface horizontal temperature distribution, in its effect on free-air pressure gradients, and the winds in the middle and upper portions of the troposphere," is further brought out.

The temperature distribution on these two dates was entirely dissimilar. On December 14, 1919, there was a very steep south-to-north temperature gradient over the eastern part of the country. This resulted in free-air pressure gradients toward the north, which became steeper with increasing altitude, and caused winds of unusual velocity in the middle troposphere. On January 29, 1919, the normal poleward temperature gradients were reversed, with high temperatures over the Dakotas and low temperatures in the Southwest. As explained in the MONTHLY WEATHER REVIEW for a similar occurrence in January, 1920 (5), this caused an elevation of the isobaric surfaces in the North and a depression in the South and Southwest, and resulted in north-to-south pressure gradients and resulting easterly winds at high altitudes over the Plains States. The last four columns of Table 5 show the deep easterly winds over Oklahoma on January 29, 1920; an account of the same phenomenon as observed at Texas stations has been referred to (5).

TABLE 5.—*Abnormal winter winds at high altitudes over Oklahoma.*

| Altitude. | Broken Arrow. | | | | | | Fort Sill. | |
|---|---|---|---|---|---|---|---|---|
| | 8 a. m., Jan. 29, 1919. | | 8 a. m., Dec. 14, 1919. | | 3 p. m., Jan. 29, 1920. | | 3 p. m., Jan. 29, 1920. | |
| | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. | Direction. | Velocity. |
| *Meters.* | | *m/s.* | | *m/s.* | | *m/s.* | | *m/s.* |
| Surface | sw. | 4 | sw. | 1 | sse. | 5 | ssw. | 3 |
| 250 | w. | 9 | nnw. | 3 | ssw. | 5 | sw. | 4 |
| 500 | wnw. | 10 | nnw. | 5 | sw. | 4 | sw. | 4 |
| 750 | wnw. | 8 | nnw. | 9 | sw. | 4 | sw. | 5 |
| 1,000 | wnw. | 7 | nnw. | 11 | sw. | 3 | sw. | 5 |
| 1,500 | nw. | 8 | nw. | 13 | sw. | 4 | ssw. | 5 |
| 2,000 | wnw. | 6 | nw. | 15 | sw. | 7 | ssw. | 4 |
| 2,500 | nw. | 7 | wnw. | 21 | wsw. | 5 | sw. | 4 |
| 3,000 | nnw. | 9 | wnw. | 26 | w. | 4 | wsw. | 3 |
| 3,500 | nw. | 8 | wnw. | 29 | wnw. | 4 | w. | 3 |
| 4,000 | nnw. | 8 | wnw. | 29 | nw. | 5 | nw. | 2 |
| 4,500 | n. | 8 | wnw. | 35 | wnw. | 7 | nnw. | 3 |
| 5,000 | n. | 10 | wnw. | 39 | wnw. | 7 | n. | 2 |
| 6,000 | n. | 6 | wnw. | [1] 50 | wnw. | 5 | ene. | 3 |
| 7,000 | ne. | 9 | ........ | ........ | wnw. | 2 | e. | 5 |
| 8,000 | nne. | 2 | ........ | ........ | ne. | 2 | e. | 10 |
| 9,000 | ne. | 3 | ........ | ........ | ese. | 4 | ene. | 7 |
| 10,000 | w. | 17 | ........ | ........ | ene. | 2 | ese. | 7 |

[1] At 5,400 meters altitude.

A few instances of extreme velocities have been recorded. On December 17, 1919, at Lansing, Mich., a velocity of 81 m/s. was observed at 6 kilometers. (6) On March 13, 1920, at Broken Arrow a velocity of 84 m/s. was observed at 6,200 meters. Such velocities are to be accepted with reservation because of the possibility of an error due to a leaky balloon, but the similarity of the surface temperature distribution and the velocities observed tends to prove the essential accuracy of these two observations. They are most unusual and occur only in the winter half-year when the pole-ward temperature gradients greatly exceed the normal. On these two dates there was a temperature difference of 56° C. between southern Florida and the northern Lake region.

## CONDITIONS UNFAVORABLE FOR FLYING.

*High winds.*—Surface winds in this region are seldom strong enough to prevent an experienced aviator from taking off or landing with safety, but winds of sufficient force to be a serious obstacle to economical flying into a head wind sometimes persist for one or two days at a time in winter and early spring. At this season the highest surface velocities generally occur from noon to 2 p. m. These winter winds, because of wide distribution and persistence, can be determined and their effect on the course of an airplane can be foretold with reasonable accuracy.

In summer, on the other hand, such winds seldom occur, but the wind feature of most danger to aviators is the squall winds that accompany thunderstorms.

These winds sometimes attain a velocity of 30 m/s. for a short time, and are most frequent from 3 p. m. to 5 p. m. Forecasts of squall winds and thunderstorms, on account of their short duration and the limited area covered, can not well be made on the Weather Bureau report, except to state that conditions are favorable for their occurrence. They usually occur in the southern quadrant of a LOW or near the wind shift line of a V-shaped depression, and move in an easterly direction over a path from a few to 500 kilometers or more, advancing at a rate of 50 to 60 kilometers per hour.

Aviators should study the structure of thunderstorms, and the direction of the attendant winds in relation to the path of the storm, bearing in mind that with the onset of the squall the surface wind usually veers from a southerly to a northwesterly direction. Dr. Brooks has pointed out the danger of attempting to fly through a thunderstorm due to lightning and the violent turbulence of the air. (7) As a rule the aviator should be able to see the approaching storm in time to make a safe landing before the arrival of the violent squall wind. Capt. C. K. M. Douglas (8) in "Clouds as seen from an Aeroplane," says: "A thunderstorm 100 miles away is a conspicuous object from the air, and the top of 'anvils' may sometimes be seen from 10,000 feet at a distance of about 200 miles. Thunderstorms can nearly always be avoided without difficulty by aeroplane pilots engaged in ordinary peacetime flying. The higher the pilot flies the more conspicuous the tops of the thunder clouds become, and the more easily can they be avoided. Sometimes there are extensive clouds at about the base of the thunder clouds and it is necessary to climb above them in order to see the thunderstorms at a distance, and to judge the best course to fly in order to avoid them."

*Fog, clouds, and rain.*—Dense fog stops flying, not only because it makes safe landing impossible, but it prevents the taking of observations of the wind aloft which would assist the aviator in steering an accurate course above the fog. Persistent fogs are, however, infrequent, and are confined mostly to early winter when the vapor content of the air is being reduced by falling temperatures. The most frequent unfavorable condition for flying is the presence of low stratus clouds, often at an altitude of less than 500 meters, and in many cases accompanied by precipitation. Flying beneath such clouds is inadvisable because of the danger of having to make a forced landing within a limited area and the chance for accident because of surface obstructions. Furthermore, intermittent precipitation when the temperature is slightly below freezing will soon cause an accumulation of ice and make a forced landing unavoidable. For a discussion of the advantages of flying above and below the clouds reference should be made to "Over-Cloud Flying and Commercial Aeronautics," Aviation, June 15, 1920.[3]

A record of the number of times that balloon runs were not made because of adverse weather gives a rough estimate of the frequency of these conditions. Table 6 gives the number of winter and summer days during the two-year period at Broken Arrow when one or both runs were not made. From this table it is seen that there are approximately 14 per cent of winter days and 7 per cent of summer days that are somewhat unfavorable for flying; and 10 per cent of winter days and 2 per cent of summer days that are decidedly unfavorable.

[3] Abstract in Mo. WEATHER REV., September, 1920, pp. 528-529.

TABLE 6.—*Number of days balloon runs were not made because of adverse weather (2-year record).*

| Cause. | Winter, October-March. | | Summer, April-September. | |
|---|---|---|---|---|
| | Observations missed. | | Observations missed. | |
| | One. | Two. | One. | Two. |
| Fog | 3 | 8 | 1 | 0 |
| Rain or snow | 22 | 16 | 9 | 5 |
| Low clouds | 25 | 13 | 15 | 3 |
| Total | 50 | 37 | 25 | 8 |

*Best altitude for flying.*—The aviator who finds himself without a daily wind report will find the tables of seasonal averages of value in selecting the best altitude for flying. In summer the wind is usually unimportant but in winter, because of the large percentage of strong westerlies aloft, the aviator will find it best to fly high, above 1,000 meters, on an eastward trip and low on a westward one. For the same reason cross winds will be encountered in north and south flying and low altitude is again advisable. However, if strong head winds are found while flying north or south the following condition is likely to occur: A rapid increase in velocity from the ground to an altitude of 500 to 1,000 meters, with a decrease, sometimes very rapid, at higher altitudes; and it will be best to try to find a region of lighter wind at elevation of 1,500 meters or more. This is an early morning condition and leads us to the next paragraph.

*Best time of day for flying.*—Flying in winter may often be done best near midday or in the afternoon because of the presence at times of morning fogs or low stratus clouds which are dissipated by the rising sun. Also, at ordinary flying altitudes wind velocities are less than in the early morning (fig. 3). In summer morning hours are best because the wind is steady, visibility is good, and local storms are not likely to occur; while in the afternoon turbulence sets in (bumpiness in flying) and this process may continue until thunderstorms are formed. Turbulence is caused by rough topography, buildings, the meeting or flowing past each other of air currents of different direction and density, and causes many of the peculiar phenomena of the air that the aviator has to face. These are dealt with fully by Prof. Humphreys, in "Physics of the Air," Chapter XI, pages 214-225. In a level country the principal cause of turbulence is daytime convection or the rising of heated air from the surface to a height of a kilometer or more by a process analogous to the rising of gas bubbles in boiling water. When a rising mass becomes large enough its upper limit is marked by a cumulus cloud. The cloud may soon dissipate or it may grow to large size, depending on the temperature and moisture of the rising air. Cumulo-nimbus clouds and thunderstorms are the culmination of this process.

Figure 5 shows to what extent the air may be disturbed by convection on summer afternoons, even though there is no approach to thunderstorm conditions. On June 25, 1920, two ascents were made at short intervals, and the position of the balloon was computed at the end of each minute by the two-theodolite method. Both balloons had nearly the same ascensional rate by formula, that of the first being 161 m/m and of the second 160 m/m. The first balloon, released at 2:46 p. m., rose at an average rate of 171 m/m, having been affected only slightly by convection. The second was released at 3:12 p. m., directly underneath a rather large cumulus cloud. A convectional gust caught the balloon as it left the ground, and from the end of the first to the third minute the ascensional rate was 422 m/m, or 264 per cent of the rate by formula. This gives an upward movement of the air around the balloon at a rate of 4.4 m/s. Such vertical gusts, usually much less marked, are the cause of "bumps" experienced on warm afternoons. If such a sustaining force were suddenly removed from an airplane the sensation would be that of a "hole in the air."

When convection is evident the air is also gusty, i. e., there is a rapid fluctuation in the horizontal or true wind velocity. In figure 5 it is seen that the velocity just off the ground drops from nearly 10 m/s. in the first ascent to less than 6 m/s. in the second.

Acknowledgment is due to Mr. W. R. Gregg for the use of the unpublished records of the Aerological Division on which the tables of average winds are based, and for valued suggestions and assistance rendered throughout

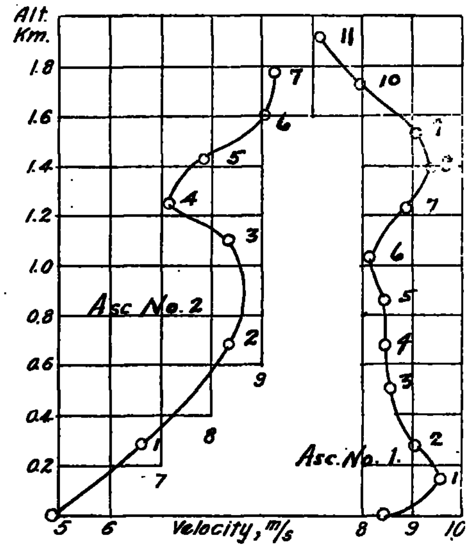


FIG. 5.—Time, altitude, velocity graph of pilot-balloon ascensions at Broken Arrow, Okla., June 25, 1920. No. 1 at 2:46 p. m. No. 2 at 3:12 p. m.

the preparation of this paper; also to the men of Broken Arrow station for the cooperation which enabled me to compute the data under conditions of very limited personnel.

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## SURFACE WINDS AND LOWER CLOUDS.

By F. E. HARTWELL, Meteorologist.

[Weather Bureau Office, Burlington, Vt., December, 1920.]

There is an unfortunate tendency among weather observers to record the lower clouds from the same direction as the surface wind. Indeed, in the writer's first lesson in taking a meteorological observation, when it came to the clouds, the entry was dictated to him: "3 stratus, SW., like the wind, *of course.*"[1]

Shortly thereafter, an intimate association with the West Indian hurricane in its own habitat indicated to him the importance of cloud drift in determination of direction of storm centers from the station, so that he has always been particularly careful to enter cloud directions from a careful sight, without reference to surface currents.

At the end of a year's work here in Burlington with pilot balloons, an examination of the record of flights made shows the fallacy of an assumption that the lower clouds, "of course," drift with the surface wind.

During the year, the actual direction of lower clouds was determined by means of balloon flights 186 times. Of these 186 only 28, or 15 per cent, were recorded the same direction as the surface wind. However, the directions in this work are recorded to sixteen points, while in ordinary meteorological observations they are recorded to only eight points. Therefore, those varying one-sixteenth either side of the surface direction must be included in determining the possible error. These bring the percentage of lower clouds with surface winds up to 38, less than four out of ten, quite a considerable error. Following the circle around, there were about one in four at a divergence of 45° from the surface wind, nearly one in three almost at right angles, 2 per cent at 135°, and 4 per cent nearly opposite.

This computation takes into consideration all directions. A segregation of the different directions is not particularly pertinent to the conclusion sought, but the deviation of the drift of lower clouds from surface wind direction varied somewhat with the surface direction, being greatest near east, and least at north. This variation would probably differ at different latitudes to such an extent that a detailed statement of it would be valueless.

The foregoing statements refer to occasions when a lower cloud direction was actually determined. The record was further examined with reference to the 500 and 1,000 meter levels, which include most lower clouds, and these results, with the foregoing, are included in the following table:

*Percentage of direction of lower clouds and of drift at selected levels compared with surface wind direction.*

| Deviation from surface direction (degrees of azimuth). | Lower clouds (186 observations). | 500-meter level (546 observations). | 1,000-meter level (495 observations). |
|---|---|---|---|
| | *Per cent.* | *Per cent.* | *Per cent.* |
| 0 (surface direction) | 15 | 20 | 14 |
| 22½ | 23 | 37 | 24 |
| 45 | 26 | 20 | 22 |
| 67½ | 17 | 9 | 16 |
| 90 | 9 | 7 | 11 |
| 112½ | 4 | 2 | 5 |
| 135 | 2 | 2 | 3 |
| 157½ | 3 | 2 | 3 |
| 180 | 1 | 1 | 2 |

[1] It is hoped that such an instruction would be exceptional among officials in charge of Weather Bureau stations at present. We know that the observers at the majority of stations take pains to observe the direction of motion of the lower clouds.—EDITOR.